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ROAD MORTALITY OF TERRESTRIAL VERTEBRATES IN INDIANA

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ABSTRACT. The State of Indiana has over 150,000 km of roads. Although the biological effects of Indiana's road network are not well-understood, the combination of intense habitat fragmentation within the state and substantial road density may have detrimental effects on many wildlife species. From 13 April 2005 to 23 February 2006, we conducted a series of statewide road mortality surveys to develop a vertebrate road mortality species index and to identify factors influencing the frequency of road mortality within the state. We established nine survey routes and sampled each route eight times over one year (two surveys per route per season). There were 563 mortality events (0.4 kills/km surveyed) representing more than 50 species recorded across the nine routes during 72 surveys. For mammals, birds, and reptiles/amphibians, respectively, the most common species encountered were Virginia opossum (*Didelphis virginiana*, $N = 179$), American robin (*Turdus migratorius*, $N = 9$), and painted turtle (*Chrysemys picta*, $N = 12$). Across routes for all species combined, mortality varied from 0.2–1.0 events per km surveyed. Road mortality was less frequent in winter than in other seasons. Our study suggests that road mortality impacts a wide variety of species from different taxonomic groups and that the frequency of road mortality varies across sites, probably due to a variety of habitat considerations, road characteristics, and attributes of local vertebrate communities.

Keywords: Automobile, Indiana, mortality, roadkill, vertebrate

The impact of humans on natural areas has intensified steadily since the advent of large-scale automobile manufacturing in the early 20th century. The increase in personal vehicles and the associated development of the road system made many formerly remote areas easily accessible to the public. Currently there are over 6,200,000 km of public roads in the U.S., used by 200,000,000 vehicles, which link essentially every local area in the nation (National Research Council 1997). Road corridors, defined as the road surface plus its maintained roadsides and parallel vegetated strips, cover about 1% of the U.S., a combined area equivalent to that of South Carolina (Forman 2000).

Many ecological effects of roads on species, soils, and water have been identified, with effects varying in distance outward from meters to kilometers (Ellenberg et al. 1991; Forman 1995). These "road-effect zones" impact an estimated 15–20% of the land mass of the U.S. (Forman & Alexander 1998). Although roads are an important part of infrastructure and can provide some ecological benefits such as maintenance of grassland plants in intense agricultural areas (Forman 2000), they also can present numerous ecological problems. For example, exotic plant species, which are planted along roads to help combat erosion, snow accumulation, and enhance aesthetics, can spread into nearby natural ecosystems (Forman 1995). Runoff pollutants from roads (primarily de-icing salts and heavy metals) can alter soil chemistry, be absorbed by plants, and affect stream ecosystems (Forman & Alexander 1998). Roads also act as both physical and biological barriers for many vertebrate species (Jackson 2000). Likewise, vehicular traffic on roads can be direct sources of vertebrate mortality and, in some instances, can be catastrophic for populations (Langton 1989).

Many researchers have recognized the realized and potential impacts of automobiles on vertebrate populations (Romin & Bissonette 1996; Trombulak & Frissell 2000; Gibbs &

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Shriver 2002). Lalo (1987) estimated vertebrate mortality on U.S. roads at 1,000,000 individuals per day. For many species, road mortality can serve as a population-limiting factor because their foraging and dispersal behaviors put them at risk of being struck on roadways. In Launceston, Australia, annual road mortality of the brushtail possum (*Trichosurus vulpecula*) exceeds the local birth rate (Statham & Statham 1997) and wildlife/vehicle collisions are the primary cause of death in moose (*Alces alces*) in the Kenai National Wildlife Refuge, Alaska (Bangs et al. 1989). Road mortality can be especially destructive to carnivores, which normally have low reproductive rates, low population densities, and large home ranges (Ruediger 1996). For example, road mortality is the third-highest cause of death for wolves in Minnesota (Fuller 1989).

From the human perspective, vertebrate road mortality can pose both safety and economic problems. Collisions with animals can result in serious injury or even death to motorists. In addition, drivers may attempt to avoid animals on the road, subsequently endangering themselves and others. Groot Bruinderink & Hazebroek (1996) estimated the annual number of collisions with ungulates in Europe at 507,000, resulting in 300 human fatalities, 30,000 human injuries, and $1 billion (U.S.) in damages. An estimated 1,500,000 animal-vehicle collisions involving deer (*Odocoileus* spp.) alone occur annually in the U.S. (Conover et al. 1995). Estimated damage to vehicles in such collisions exceeds $1.1 billion in total and averages approximately $1500 per collision (Conover et al. 1995). Conover et al. (1995) reported that deer/vehicle collisions resulted in over 29,000 human injuries and over 200 fatalities annually in the U.S. Overall, human injury results from approximately 4% of collisions involving medium-sized animals (Conover et al. 1995) and 14–18% of collisions with larger animals such as moose and deer (Farrell et al. 1996). These figures do not account for losses due to collisions with other wildlife and only represent reported animal-vehicle collisions.

In Indiana, information regarding road mortality of wildlife is lacking. Other than annual raccoon road mortality surveys for population estimation conducted by the Indiana Division of Fish and Wildlife, no regular surveys have been attempted. Here, we present a statewide pilot study of road mortality in Indiana. Our objectives were to determine which species are most heavily impacted by road mortality and to identify factors influencing the frequency of road mortality within the state.

METHODS

We identified potential survey routes throughout Indiana using state topographic maps (scale 1:156,000) and by consulting with regional biologists. We primarily focused on state and federal roads. Survey routes were more than 10 km in length and were chosen to represent a mixture of geographic and anthropogenic conditions (e.g., upland and wetland, rural and suburban) and to cover northern, central, and southern portions of the state (Table 1; Fig. 1). Survey routes also were chosen based on safety and accessibility (e.g. available shoulder, visibility). Overall, nine survey routes were selected covering a total of 158.5 km. Available annual daily traffic volume data (surveys from 2001–2004) for survey routes were acquired from the Indiana Department of Transportation.

Road mortality detection surveys were performed between 13 April 2005 and 23 February 2006 on all selected routes. Routes were driven at slow speeds (less than 40 km/h) to allow for better detection of carcasses. We sampled each route twice during each of four seasons (spring 2005, summer 2005, fall 2005, and winter 2006) for a total of eight samples per route. Surveys were conducted approximately three weeks apart during each season.

Surveys accounted for all carcasses found within the road shoulders. All carcasses were identified to species (whenever possible), marked (via spray paint) or removed to avoid recounting, and their locations entered into a Trimble GeoXT GPS system. Carcass location data points were downloaded to a personal computer using TerraSync and GPS Pathfinder Office software (Trimble 2003). Carcasses in excellent condition were donated to the vertebrate collection at Purdue University. All identified road mortalities were compiled in a species index. We used a Chi-square test to examine seasonal differences in the total number of carcasses encountered across all routes.

Because of the slow speeds necessary for effective surveying and the surveyor's proximity to roads when marking individual carcasses, safety was a top priority. Safety orientation was completed via an on-line video from the Joint

Table 1.—Characteristics of vertebrate road mortality survey routes in Indiana. Data are from Indiana Department of Transportation traffic surveys, 2001–2004. NA = not available.

Site	Survey route	Length (km)	Site description	Road characteristics	Urbanization level	Mean daily traffic
South Bend	SR 4 from US 31 to SR 104	25.7	Potato Creek SP; mixed hardwoods and fields: some wetlands	2-lane paved road; shoulder varies	suburban-rural	1712
DeKalb	Old State Hwy 47 from 11A Rd to Popp Rd	16.1	Primarily fields; mixed hardwoods; route crosses 3 small creeks	2-lane paved road; portions of large shoulder	rural	NA
Warsaw	SR 5 from CR 750N to US 33	19.3	Tri-County FWA; route adjacent to 4 large lakes; mostly open/ ag fields	2-lane paved road; little shoulder	urban-suburban-rural	2195
Anderson	CR 200E (old SR 67) from US 36 to CR 500E	14.7	Mounds State Park; some hardwoods; mostly open/ fields	2-lane paved road; shoulder varies	urban-suburban-rural	NA
Richmond	SR 101 from Fosdick Rd. to Golden Rd	17.4	Brookville Lake Project; some mixed hardwoods, mostly open/ fields	2-lane paved road; portions of large shoulder	suburban-rural	3468
Greencastle	SR 59 from CR 720S to US 36; US 36 from SR 59 to CR 850W	19.6	Cecil M. Harden Lake Project; mixed hardwoods to fields	2-lane paved road, shoulder varies	suburban-rural	3023
Greenwood	SR 135 from SR 44 to SR 144; SR 144 to SR 44	15.6	Mixed hardwoods and open/fields; route crosses several creeks	2-lane paved road; portions of large shoulder	urban-rural	7097
Sellersburg	SR 160 from I 65 to Blue River Rd	10.5	Clark State Forest; mixed hardwoods, some fields	2-lane paved road: shoulder varies	suburban-rural	1795
Huntingburg	SR 162 from SR 245 to US 231; SR 62 from US 231 to Frog Pond Rd	19.6	Lincoln State Park; mixed hardwoods, some fields: wetlands bisected by SR 62	2-lane paved road: large shoulder for most of route	suburban-rural	2508

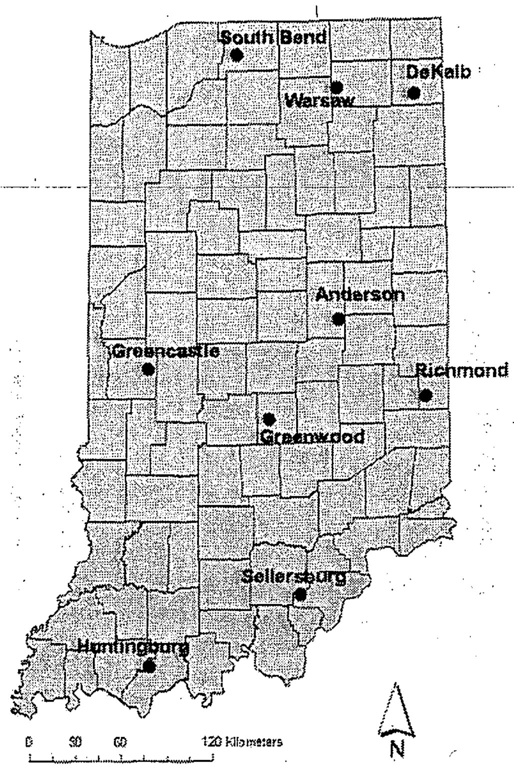

Figure 1.—Locations of vertebrate road mortality survey routes ($n = 9$) in Indiana.

Transportation Research Program at Purdue University. All surveying vehicles were equipped with amber beacons and flashers and any surveyor exiting the vehicle along a route wore a high visibility safety vest. In addition, signs were posted when necessary to alert oncoming traffic of surveying activity.

RESULTS

From 13 April 2005–23 February 2006, we conducted 72 surveys encompassing 1268 km of roadway (occasionally surveys were truncated due to inclement weather). Across all 9 routes, we recorded 563 road-mortality events, for an average of 0.4 events per km per survey. Of these, 457 individuals were mammals, 51 were birds, and 55 were reptiles or amphibians (Table 2). The total number of road mortalities across all routes varied by season, with the fewest number of mortalities documented during the winter ($\chi^2 = 52.59$, $P < 0.0001$; Fig. 2).

At least 52 species were represented among the road mortalities (20 mammals, 19 birds, 13 reptiles or amphibians) (Table 3). The most commonly identified mammal, bird, and reptile/amphibian species, respectively, were Virginia opossum (*Didelphis virginiana*, $N = 179$), American robin (*Turdus migratorius*, $N = 9$), and painted turtle (*Chrysemys picta*, $N = 12$). The routes with the highest mean number of mortalities per km were DeKalb (1.0), Anderson (0.6), and Richmond (0.5). The routes with the lowest mean roadkill per km were Sellersburg (0.2), Warsaw (0.3), and South Bend (0.3) (Table 2).

DISCUSSION

Opossums ($N = 179$) and raccoons (*Procyon lotor*; $N = 144$) comprised over 50% of all detected carcasses, and white-tailed deer, often synonymous with wildlife/vehicle collisions, comprised only 4% ($N = 22$) of the total. The high numbers of opossums and raccoons may have reflected their large population sizes in Indiana. We found no population estimates for

Table 2.—Vertebrate mortalities and kills per km surveyed by taxonomic group for nine Indiana survey routes, 13 April 2005–23 February 2006.

Route	Mammals	Birds	Reptiles and amphibians	Total	Route length (km)	Number of surveys	Total km surveyed	Kills/km surveyed
South Bend	61	2	2	65	25.7	8	205.6	0.3
DeKalb	117	7	11	135	16.1	8	128.8	1.0
Warsaw	31	6	3	40	19.3	8	154.4	0.3
Anderson	59	6	0	65	14.7	8	117.6	0.6
Richmond	49	11	11	71	17.4	8	139.2	0.5
Greencastle	51	5	6	62	19.6	8	156.8	0.4
Greenwood	44	8	0	52	15.6	8	124.8	0.4
Sellersburg	10	1	4	15	10.5	8	84.0	0.2
Huntingburg	35	5	18	58	19.6	8	156.8	0.4
Total	457	51	55	563	158.5	72	1,268	0.4

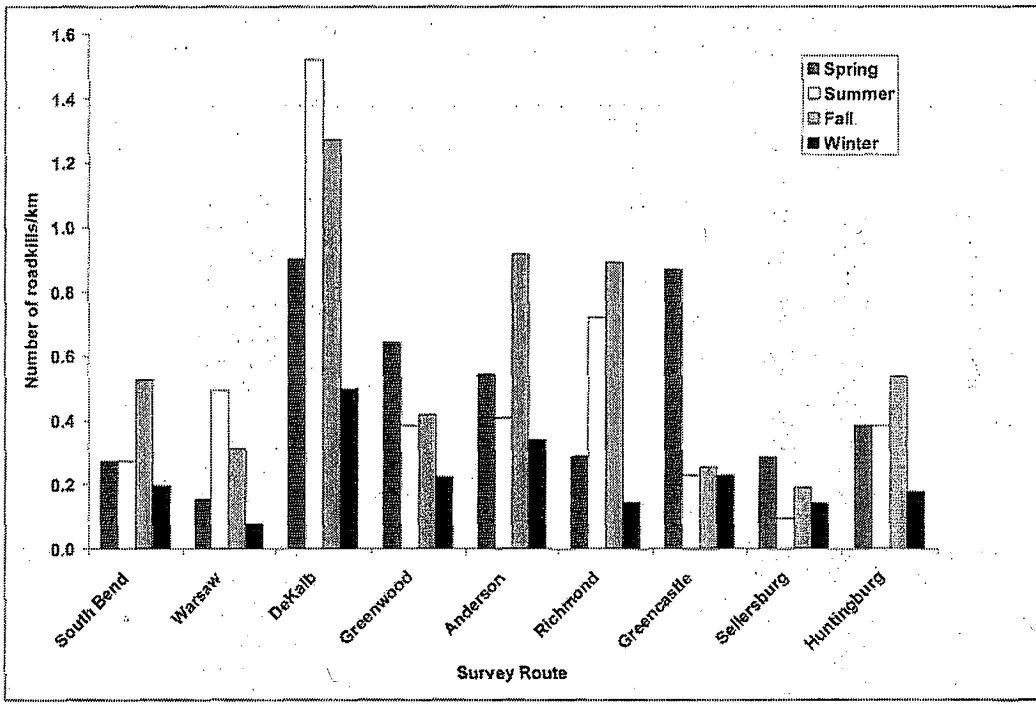

Figure 2.—Seasonal wildlife mortalities on Indiana roads, spring 2005–winter 2006 (spring = March, April, May; summer = June, July, August; fall = September, October, November; winter = December, January, February).

opossums in Indiana, but according to the annual raccoon roadkill survey conducted by the IDFW, there was a 28% decrease in raccoon road mortalities in 2006 compared to 2005 (Plowman 2006). The IDFW surveys also exhibit a downward trend in raccoon road mortalities since 2003, suggesting an overall decrease in the raccoon population in Indiana.

Although road mortality may not affect populations of abundant species, it can have a substantial impact on populations of threatened or endangered species. Of the 50 species found dead along roads in the present study, at least two are of conservation concern (*Lasiurus borealis* and *Rana pipiens*) in Indiana (Table 3). Other documented examples of the negative impact of road mortality on threatened or endangered populations include the eastern barred bandicoot (*Perameles gunnii*) in Victoria, Australia (Brown 1989) and the endangered Florida panther (*Felis concolor coryi*) (Foster & Humphrey 1995; Evink et al. 1996). Road mortality also serves as a limiting factor in the recovery of the American crocodile (*Crocodylus acutus*; Kushlan 1988) and as a contributor to the endangerment of the prairie garter snake (*Thamnopsis radix radix*) in Ohio (Dalrymple & Reichenbach 1984).

The seasonal sampling regime provided a species index of road mortality but limited our ability to make inferences about biological effects. For example, movements in amphibians often are associated with breeding migrations and/or weather-related events (Langton 1989). We likely missed such movements in our surveys because of seasonal sampling. The biological ramifications of amphibian movements during these times can be important. Where amphibians must migrate across roads to reach breeding ponds, mortality of breeding adults can reach 20–40% (Langton 1989). With female ambystomatid salamanders producing (on average) over 1000 eggs per individual and anuran egg numbers ranging from several hundred (in smaller hylids) to several thousand in larger ranids and bufonids (Wright & Wright 1949; Harding 1997), road mortality of migrating gravid females has the potential to remove thousands of juvenile salamanders, frogs, and toads from their populations.

Table 3.—Vertebrate carcasses recorded along nine survey routes in Indiana, 13 April 2005–23 February 2006. Note that the eastern red bat and the northern leopard frog are species of special concern in Indiana, and that eastern box turtles are protected.

Scientific name	Common name	Total
Mammals		
Canis familiaris	domestic dog	2
Canis latrans	coyote	2
Didelphis virginiana	opossum	179
Felis catus	cat	20
Lasiurus borealis	eastern red bat	1
Marmota monax	woodchuck	5
Mephitis mephitis	striped skunk	18
Microtus pennsylvanicus	meadow vole	1
Mustela vison	mink	4
Odocoileus virginianus	white-tailed deer	22
Ondatra zibethicus	muskrat	2
Peromyscus spp.	deer/white-footed mouse	6
Procyon lotor	raccoon	144
Rattus norvegicus	Norway rat	1
Scalopus aquaticus	eastern mole	1
Sciurus carolinensis	eastern gray squirrel	3
Sciurus niger	fox squirrel	15
Spermophilus tridecemlineatus	13-lined ground squirrel	1
Sylvilagus floridanus	eastern cottontail	23
Vulpes vulpes	red fox	1
	unknown mammal	6
Total		457
Birds		
Accipiter cooperii	Cooper's hawk	1
Agelaius phoeniceus	red-winged blackbird	1
Anas platyrhynchos	mallard	1
Cardeulis tristis	American goldfinch	2
Cardinalis cardinalis	northern cardinal	3
Chaetura pelagica	chimney swift	1
Falco sparverius	American kestrel	1
Junco hyemalis	dark-eyed junco	1
Meleagris gallopavo	wild turkey	1
Melospiza melodia	song sparrow	3
Mimus polyglottos	northern mockingbird	2
Passer domesticus	house sparrow	6
Passerina cyanea	indigo bunting	2
Poecile atricapillus	black-capped chickadee	1
Quiscalus quiscula	common grackle	1
Sturnus vulgaris	European starling	2
Turdus migratorius	American robin	9
Tyrannus tyrannus	eastern kingbird	1
Zenaida macroura	mourning dove	1
	unknown bird	9
	unknown swallow	1
	unknown sparrow	1
Total		51
Reptiles and Amphibians		
Bufo americanus	American toad	1
Chelydra serpentina	snapping turtle	2
Chrysemys picta	midland painted turtle	12
Coluber constrictor constrictor	northern black racer	1

Table 3.—continued.

Scientific name	Common name	Total
Coluber constrictor foxii	blue racer	2
Elaphe obsoleta	black rat snake	3
Lampropeltis getula nigra	black king snake	1
Lampropeltis triangulum	eastern milk snake	1
Rana catesbeiana	bullfrog	1
Rana pipiens	northern leopard frog	1
Rana spp.	unknown ranid	3
Terrapene carolina	eastern box turtle	9
Thamnophis sirtalis	garter snake	6
Trachemys scripta	red-eared slider	4
	unknown frog	6
	unknown turtle	2
Total		55
Grand total		563

Our seasonal sampling regime certainly contributed to a bias towards detection of larger carcasses (e.g., white-tailed deer, raccoons, and opossums) and a reduced number of smaller carcasses such as birds and amphibians. Mammals accounted for the majority of detected carcasses, in part due to their larger size and greater resistance to degradation. Carcass degradation was a constant problem for reliable sampling, especially during the summer months, and at times made positive identification difficult. Moreover, some carcasses may have been eaten by scavengers prior to marking and some animals may have left the roadside after being hit (Smith & Dodd 2003). Carcass removal by other means (such as road crews and snow removal equipment) also may have affected our results.

Overall, this statewide pilot study confirmed that road mortality impacts a wide variety of species from different taxonomic groups (Table 3) and that road mortality incidence varies across sites, probably due to habitat considerations and traffic characteristics. Our estimate of 0.4 road mortalities per km, extrapolated across the 150,000 km of roads in Indiana, equates to roughly 60,000 animals killed statewide during our sampling periods. On an annual basis, this number is undoubtedly many times higher. Our results indicate that mid-size mammals (e.g., opossums and raccoons) comprised the majority of road mortalities and that smaller animals (small mammals, birds, reptiles, and amphibians) were inherently difficult to detect with this type of infrequent sampling regime. This ascertainment bias towards large carcasses suggests that collecting data for smaller species (e.g., amphibians) requires more intensive sampling (Glista 2006), in part because of detection issues but also because many small species are seasonal migrants. Thus, they may be impacted disproportionately at certain times of the year, or even certain days.

In conclusion, the broad survey of road mortality described in this statewide pilot study suggests that 1) vertebrate road mortality is a very real problem in Indiana, and 2) monitoring protocols must be established based on the taxonomic group of interest, particularly with regard to quantifying road mortalities and/or determining key habitat (Glista 2006). Additional studies, especially those than span several years, would be beneficial to land managers and lead to greater awareness of this problem.

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